The resource constraint can be given a specific formulation:

$$I = y + C(X, s) / s$$

where *i* is the individual's income, the price of the private good is one, and *C(X,s)* is the club's cost. Club cost depends positively on both the size of the shared facility and the number of members; this latter influence reflects maintenance costs associated with utilization.[98] Dividing club costs by the membership size indicates that club costs are equally shared.

To find the optimal provision and membership requirements, a representative member is depicted as maximizing his or her utility function subject to the resource constraint. First-order conditions are:

$$(MRS_{Xy}) = U_X / U_y = C_X / s \qquad \textit{(Provision)}$$
$$(MRS_{sy}) = U_s / U_y = [\, s\, C_s - C(\cdot)\,] / s^2 \qquad \textit{(Membership)}$$

where subscripts on the *U*'s and *C*'s denote partial derivatives.

For the provision condition, the MRS between the two goods is equated with the individual's share of the marginal costs of provision. Optimal membership requires an equality between the relevant MRS and the marginal costs of increasing membership size. The latter includes increased maintenance fees and reduced membership fees owing to sharing. In this alternative representation, full financing always results since the budget constraint divides the club costs among the members.

Applications

The origins of club theory can be traced to the works of A.C. Pigou (1920) and Frank Knight (1924) on tolls for congested roads. By determining the tolls on the congested road Pigou and Knight were essentially solving a club problem, since the toll would restrict users, and thereby determine "membership size" for the congested highway.[99] Charles Tiebout in his "voting-with-your-feet" hypothesis attempted to show how jurisdictional size

98. The model is a slight variant of the Berglas (1976) model.

99. For a modern treatment of this problem, see Edelson (1971) and Weitzman (1974).

of local governments are determined by voluntary mobility decisions.[100] The Tiebout model is akin to homogeneous or mixed population situations in which individuals are partitioned into clubs, each containing homogeneous members. Wiseman (1957) examined a club principle for sharing costs among users of a public utility. Mancur Olson (1965) and James Buchanan (1965) recognized that clubs would form to exploit economies of scale and to share public goods. The Buchanan paper[101] bridged the gap between private and public goods envisioned by Samuelson[102] and inspired a vast literature.

Applications of the club good concept use the theory to examine toll schemes, provision level, and membership size for club goods subject to congestion, such as recreation areas, highways, and public utilities. A long-standing problem in public utility economics concerns pricing under conditions of decreasing average cost. A nonlinear price structure consisting of a flat fee and usage sensitive prices can be interpreted as a club entrance or licenses fee and a toll per unit of utilization. Ng and Weisser (1974) considered a uniform license fee across consumers and derived the Pareto-optimal toll, license fee, and membership size.

The telephone has received considerable attention with respect to the size of the sharing group. Artle and Averous (1973) maximized the net benefits of both subscribers and nonsubscribers and were the first to derive the correct Pareto-optimal membership size condition for a single club. The benefit enjoyed by a subscriber includes both making and receiving calls. Squire (1973) used a benefit function that depends on utilization of the phone and the number of other subscribers and then derived provision, membership, and toll conditions on the basis of these benefits. The growth of the telephone system was discussed in a dynamic model by von Rabenau and Stahl (1974). Rohlfs (1974) also examined telephone growth by analyzing in greater detail the demand for service.

Club good and network externality theory can be used to provide policy guidance leading to an appropriate and efficient market structure for local telecommunications services. Starting with the pre-*Carterphone* local telephone monopoly, we note that CPE exhibits properties of both rivalry in consumption as well as divisibility and excludability of benefits. While certain manufacturing economies may exist in this as in most other manufactured product markets, CPE does not come even close to resembling a public good; accordingly, there is no basis upon which public utility status should be applicable.

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100. C. M. Tiebout (1956), "A Pure Theory of Local Expenditures," *Journal of Political Economy*, 64, 416-24.

101. J. M. Buchanan (1965), "An Economic Theory of Clubs," *Economica*, 32, 1-14.

102. P. A. Samuelson (1954), "The Pure Theory of Public Expenditure," *Review of Economic and Statistics*, 36, 387-89, and P. A. Samuelson (1955), "A Diagrammatic Exposition of a Theory of Public Expenditure," *Review of Economics and Statistics*, 37, 350-356.

Looking at the other elements of local telephone service — access links ("loops") and local switching, we observe distinctly different properties. In the case of loops, which also exhibit rivalry in consumption, there are clearly scale economies due to the high fixed costs of distribution cables and associated supporting structures, such that up to a point membership growth will result in lower per-unit cost. However, the capacities of these facilities are finite, and congestion will set in, for example, if substantial demand develops for additional access lines furnished to the same household. Without the connectivity that is accomplished in the separate *switching* function, there are no consumption externalities, *per se*, associated with access lines other than the sharing of fixed costs across a larger population of users. Accordingly, under certain conditions, the optimum size of this access line "club" may be finite, particularly where both static and dynamic efficiencies resulting from increased competition are considered.

The situation is distinctly different with respect to the local switching function. First, unlike relatively low-capacity loop cables, local switching and interoffice trunking networks are engineered for extremely high volumes of traffic, utilizing fiber optic facilities with near-infinite (relative to typical demand) call carrying capacities. Hence, decreases in average unit cost arising from membership growth will dominate and overwhelm any minor amount of congestion that might arise. Second, substantial consumption externalities associated with the *connectivity* provided by the local switching network will result in continuing growth in benefits as membership expands. Indeed, even where benefit growth approaches zero (as membership approaches universality), the *relative* benefit from membership in this single large "club" will easily dominate the absolute benefit that a consumer would obtain by discontinuing membership and instead joining a much smaller club. Mandatory interconnection between various access link systems and the local switching network clearly facilitates competition in the access link market, but in no sense alters the fundamental switching monopoly that club good theory suggests may persist, perhaps in perpetuity.

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3 ALTERNATIVE LOCAL DISTRIBUTION AND ACCESS TECHNOLOGIES

Chapter 2 describes the public network of the future as being a "geocentric," not a "geodesic," network. The geocentric network is shown in Figure 2.12. In this network, a variety of distribution (access[103]) networks, potentially supplied by a number of competing entities, will provide service to customers. Such a distribution network may provide the equivalent of local exchange service between its own customers. More importantly, however, given the limited customer base that any one such provider other than the LEC is likely to serve well into the future, each competitive distribution network must connect the customers it serves to all other local, interexchange, and global networks. As Chapter 2 emphasizes, local interconnection can only feasibly be provided through the interconnected local switching and transport "hubs"[104] maintained by the existing LECs. Indeed, in many cases, the LEC exchange networks are likely to be involved even in completing calls between two customers of the same alternative provider. Thus each LEC local exchange network occupies the position of being a "network of networks" in the area it serves; this is the origin of the term "geocentric." As the provider of the network of networks, the LEC will be able to continue its local exchange monopoly.

One primary class — in fact, the dominant class now and well into the future — of distribution network provider consists of the LECs themselves. The question then becomes, to what degree can other providers successfully compete with the LECs, who are able to bundle their distribution network with the interconnecting network that all other distribution network providers must also utilize. The question has both technical, economic, regulatory, and policy aspects.

This chapter identifies and analyzes potential architectures and associated technologies that might be used by a new entrant to provide telephone service to fixed locations.[105] It develops an assessment of the per-subscriber and lump-sum capital investments associated

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103. Not to be confused with the current narrow use of the term "access" as referring only to interexchange carrier access.

104. The distinction between switches and hubs is that the former establish connections on a per-call basis, based on the digits dialed by the caller, while the latter serves to cross-connect circuits on a more semi-permanent "service order" basis.

105. While such an entrant might also be providing, for example, mobile telephone and/or data services, we consider only the fixed-location portion of its business.

with these alternative technologies, identifies the nature of expenses associated with the provision of the alternative exchange service. The results of this chapter are useful in their own right in estimating the relative capital requirements of various distribution technologies. They also form a key input to the business case analysis presented in Chapter 5. The chapter considers the following distribution architectures and technologies:

- Cellular mobile telephone;
- Personal Communications Service (PCS);
- Telephony over a cable television network, hereafter referred to as cable telephony; and
- Fiber rings provided by Competitive Access Providers (CAPs).

It also considers combinations of the above. It proceeds in the following fashion. First, it introduces a generic distribution network model that allows all technologies to be considered on a common footing. Second, it describes each of the technologies in turn, relating the technologies to the generic model. Third, it develops the capital investment associated with the various technologies, presenting them in terms of the generic model in a form which allows for straightforward comparisons between them. In doing so, it draws a comparison with commonly-cited industry figures. Finally, it draws several conclusions preparatory to the subsequent business case analysis in Chapter 5.

3.1 A Generic Model of Distribution Technologies

In order to later present investment data in a manner which facilitates a comparison between various distribution technologies, we have developed a generic model for distribution technologies, as portrayed in Figure 3.1. It depicts a common architecture that can be applied, with some care, to all of the alternatives we consider. On the right side of the figure are shown the actual technology components that must be accounted for in developing technology costs.

Starting from the customer's premises (see bottom of Figure 3.1), there is a Customer Interface Unit (CIU), which is used to derive service for that premises. Since we are considering a scenario in which the alternative technology is used to provide fixed-location telephone service, as opposed to mobile service, our treatment assumes the use of existing inside wiring and telephone terminal equipment, and excludes the costs of such components from the analysis. The CIU terminates the distribution facility and presents the appropriate standard interface to wiring and equipment at the premises.[106]

The CIU is connected to the remainder of what is called the customer connection

106. E.g., in the case of telephony, an RJ-11 jack.

(CCO). This facility may either be a "wireline" medium, consisting of copper wire pairs, coaxial cable, or fiber optics cable, or it may be wireless. In the last case, it consists of a through-the-air radio signal, and the CIU includes an antenna and transceiver.

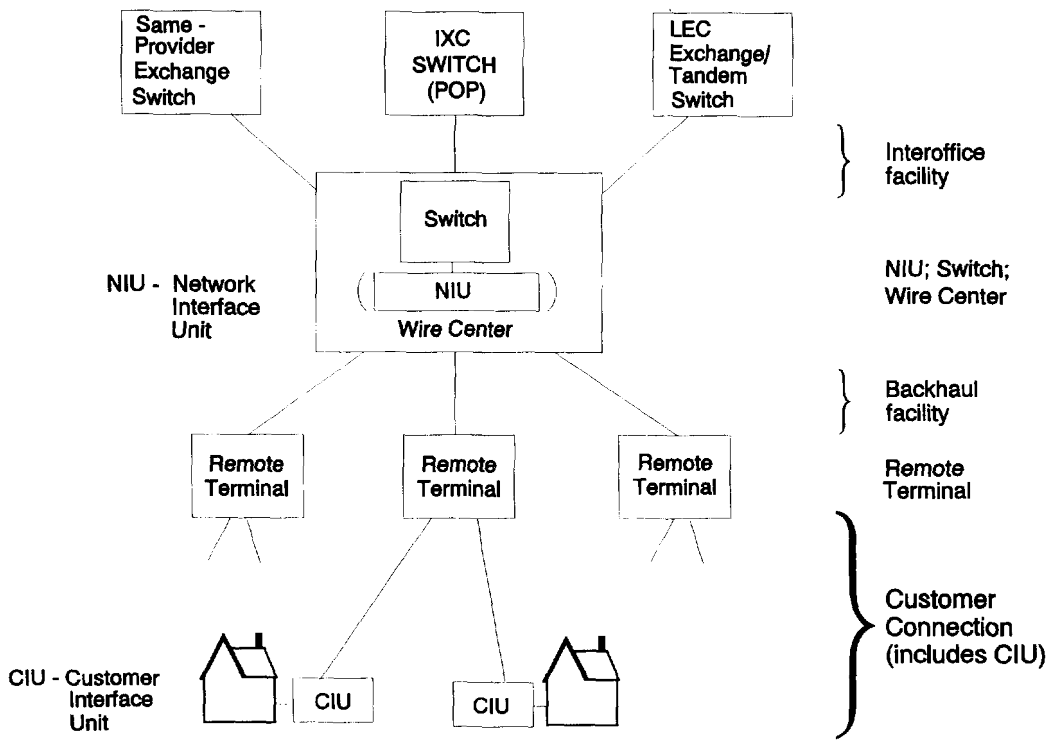

Figure 3.1. A Generic Distribution Technology Model

Although one might portray the CCO as connecting the premises directly to the wire center, it is useful for all the technologies considered to include an intermediate point called the remote terminal, at which the CCO terminates. This is done because, for all technologies considered, including LEC networks, there is a point at which at least one of the following occurs: the transmission medium changes (e.g., from wireless to wireline, or copper wires to fiber optics), there is a cross-connection to provide more flexibility in service provisioning, or the format of the signals between the network and the premises changes. Typically, this leads to a different cost treatment for the parts of the network located on the two sides of this device.

The Remote Terminal (RT) is connected to the exchange switch over a "backhaul" transmission facility. The backhaul facility is considered to include any transmission equipment required in the wire center necessary to properly terminate the facility.

The exchange switch is shown as being located in a wire center. This is done by way of emphasizing that: 1) the switch is located in a building on a parcel of land, both of which represent a considerable investment; and 2) associated with the switch is a large collection of other items of equipment, ranging from multiplexers and other transmission gear to such mundane but important elements as electrical powering, environmental control, and cross-connection frames. Some of the technologies considered require special equipment in the wire center or special switch software — such as the software which controls the "hand-off" of mobile calls from one radio site to another. Such equipment or switch software is referred to in the figure as the network interface unit (NIU), recognizing its role in isolating the rest of the switch from the specific technology used for the CCO.

The exchange switch establishes connections between calling and called customers in response to dialing instructions received from the caller. In order to permit connection to the universe of telephone customers, it must be connected to other switches, including those belonging to the same provider, to the LECs, and/or to an Interexchange Carrier (IXC) or other partner of the provider. The connecting circuits are referred to as the interoffice facility. In addition to calls to and from other switches and networks, provision must be made for signaling[107] between the various switches. In a modern telecommunications network, such inter-switch signaling takes place over a signaling network that is distinct from the call-carrying network. This is portrayed by the dotted lines associated with the interoffice facility. In reality, signaling must also take place between the premises and exchange switch, but this is normally done over the same circuits that carry calls, so such signaling is not shown separately.

Figure 3.1 shows the other end of the interoffice facility as being connected to any of the entities identified above — that is, to another switch belonging to the same alternative distribution network, an LEC local or tandem switch, or an IXC switch at the IXC's point of presence (POP). The latter two types of connection emphasize that to be viable, the distribution network must provide interconnection with the rest of the world. The cost of such interconnection must be considered in analyzing the alternative technology.

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107. Signaling refers to the process by which one switch or network element communicates with another, typically to indicate a call is being initiated or terminated, to convey the digits dialed by the calling customer, to invoke particular call features, and the like.

Having described this generic model, we now consider each of the target distribution technologies identified earlier in this chapter, as well as combinations of those technologies.

3.2 Existing Cellular Radio

Figure 3.2 shows the overall structure of a cellular mobile telephone system. Such a system comprises five classes of components: 1) the Mobile Switching Center (MSC) that controls the system, switches subscriber connections to trunks connected to LEC and IXC networks, and switches intra-system calls; 2) the cell sites, which are radio base stations containing varying numbers of radios according to local subscriber traffic requirements; 3) the backhaul facilities that connect the MSC to the cell sites; 4) interoffice transmission facilities which connect the MSCs to each other and to other carriers' networks; and 5) subscriber radios, which may be relatively high-powered units mounted in vehicles or lower-powered portable units.

The MSC connects with the network of the local exchange carrier (LEC) using any of three types of interface. It also connects with interexchange carriers' facilities at Points of Presence (POPs) via the LEC tandem or by direct interLATA connecting trunks. The interoffice circuits may be obtained from the LEC or from a fiber ring provider.

Cellular operators typically have been assigned central office codes[108] by the LEC that makes numbering assignments, and these codes generally "reside" in the MSCs, just as the codes assigned to LECs reside in exchange switches. Thus, an MSC has the same status in the switched network as an LEC's local switch.

Figure 3.3 shows the premises end of the cellular radio system in more detail, emphasizing that in this analysis, the system is considered to be providing fixed telephone service. The CIU in this case consists of an antenna, typically mounted to the outside of the premises, and a unit containing the transceiver and providing a standard telephone interface, into which the existing inside wiring is plugged. This configuration permits the use of the same terminals — telephone sets, answering machines, and so on — normally associated with wireline service. Thus no component cost is later attributed to the terminal equipment itself.

Treating the premises wiring and equipment in this fashion facilitates the comparison

108. The central office code, often referred to the "NXX" code, consists of the three digits that follow the area code in a telephone number. It is used by the network to determine the switch within the area code to which a call is to be routed.

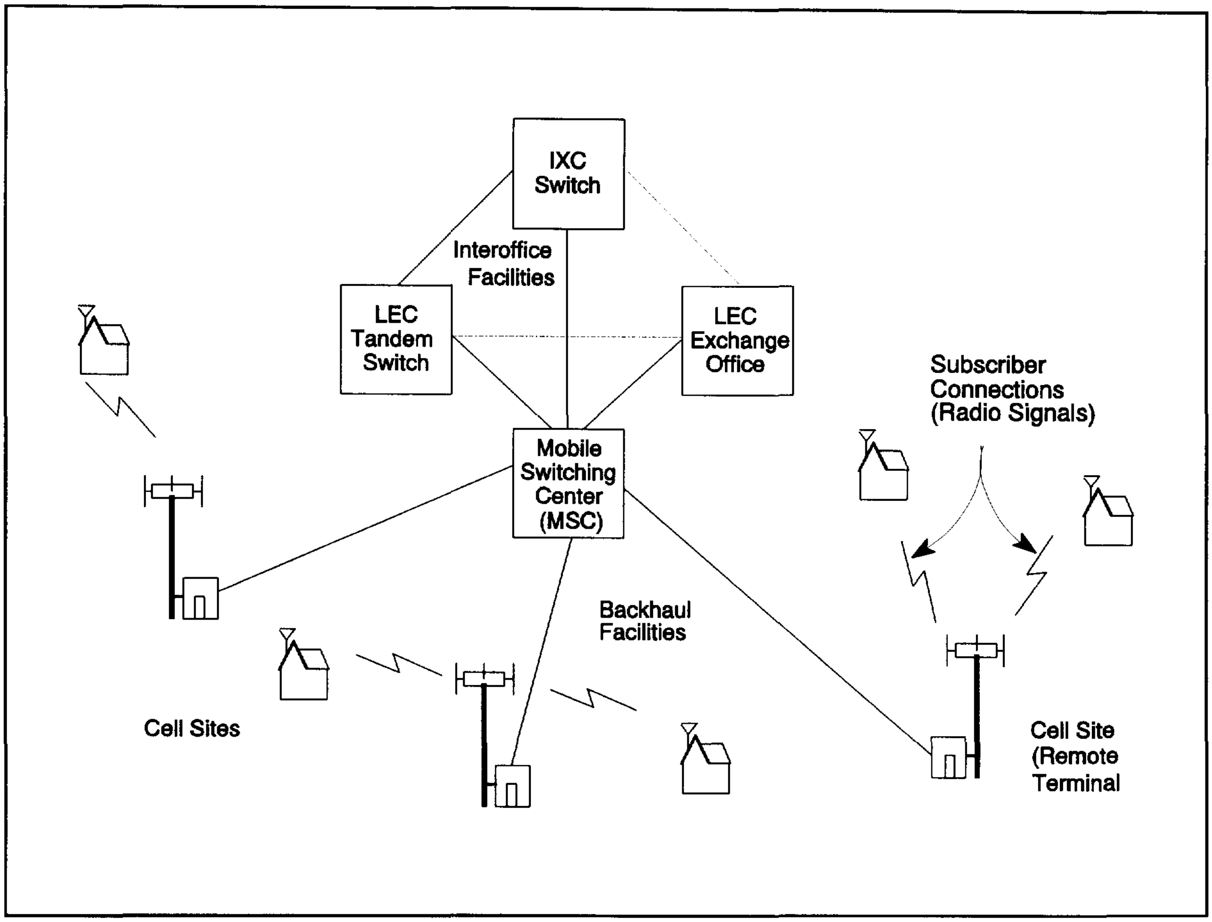

Figure 3.2. Cellular/PCS System Architecture

between alternative technologies, and separates the costs associated with the wireless network itself from the cost of terminal equipment. It should be emphasized, however, that a wireless service may be attractive to potential local exchange customers because it would allow those customers to obtain both fixed ("tethered") and mobile services from one entity, in which case the customers might willingly incur a cost premium associated with mobile terminal equipment.

In assessing the potential of a wireless system to provide fixed telephone service, one must use the usage level associated with normal telephone service. These volumes are considerably higher than those associated with today's cellular service, or projected for PCS. Thus, our analysis, rather than the busy hour utilization figure for cellular of .02 erlang, or 0.72 CCS,[109] we use the figures of 0.10 erlangs, or 3.6 CCS, for residential

109. An *erlang* is a measure of the fraction of time that something is utilized. Thus, the cellular subscriber usage of 0.02 erlangs in the busy hour means that, on average, a subscriber uses airtime for 0.02 times 60 minutes, or 1.2 minutes, during (continued...)

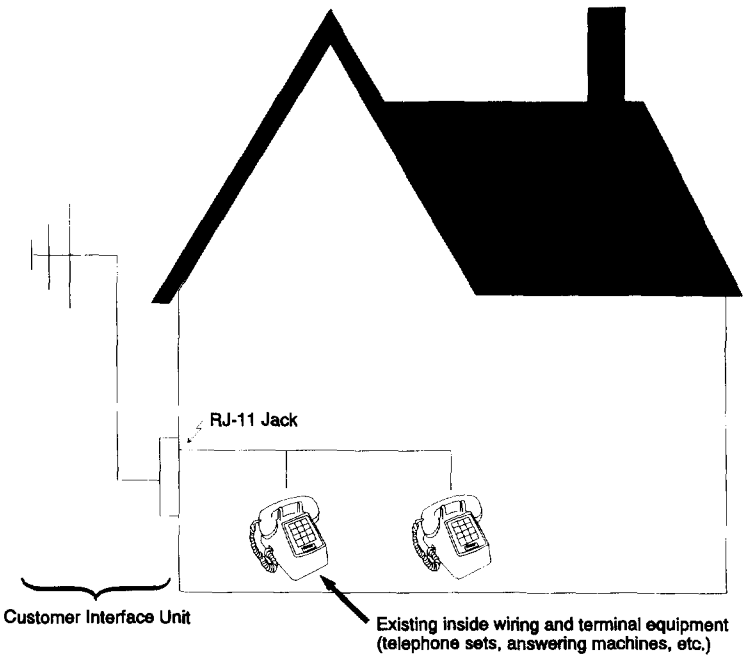

Figure 3.3 Subscriber Premises for Cellular/PCS System

local exchange subscribers, and .15 erlangs, or 5.4 CCS, for business customers.[110] *Some existing analyses of the use of cellular radio or PCS for fixed-location service ignore this critical difference.*

3.3 Personal Communications Service (PCS)[111]

The basic functional structure of a PCS system is identical to that for cellular systems, especially when it is deployed to provide local exchange service to fixed locations, as assumed in this report. Therefore, Figure 3.2 is applicable as well to PCS.

109. (...continued)
the busy hour. The term "ccs" stands for hundreds of call seconds per hour. In an hour, there are 36 periods of 100 seconds duration; thus 36 ccs represents full usage.

110. *See*, e.g., "Personal Communications Service (PCS) Network Access Demand Model & Capacity Analysis," Bellcore Special Report SR-INS-002603, Issue 1, April, 1993.

111. The FCC's attitude towards the use of PCS strictly to provide telephone services for fixed locations is uncertain. Our assumption is that in any case, PCS operators serving fixed locations would also still provide mobile service as well.

The general view of PCS systems is that they can serve considerably more subscribers than cellular systems of the conventional variety. This is partly due to the possibility of using considerably smaller cell sites and lower-power radiation, resulting in greater frequency reuse; and partly because of the use of spread spectrum and other digital transmission technologies that increase the efficiency of spectrum utilization. At the same time, the radiated power limits established by the FCC have been set high enough to allow large cell sites in initial deployments serving a small number of customers. This addresses an early concern with PCS that a large number of cell sites might need to be deployed to serve only a few customers, which could have made the price per subscriber inordinately high for the early base of customers.[112]

Our subsequent analysis shows substantial cost differences between PCS and existing cellular systems. This is consistent with a recent article which suggests that the potential infrastructure cost for PCS systems will be 25 to 75 percent lower than for cellular systems.[113]

3.4 Telephony on Cable Networks

A typical cable television network is shown in Figure 3.4. Its most notable feature is its tree and branch architecture, which is well-suited for the one-way delivery of the same signal to all served premises — for which cable networks were originally designed. Coaxial cable is the primary transmission technology used in this architecture.

Two significant problems are manifest in the figure. First, the signal must traverse a long string, or cascade, of broadband amplifiers as it travels from the headend (the signal source) to most premises. These amplifiers, spaced 1200 to 2000 feet apart, are needed due to the rapid attenuation of the broadband signal as it traverses the coaxial cable. This amplifier cascade significantly limits the capacity of the system. It also introduces significant signal degradation — noise and various forms of distortion — so that the delivered quality of the signal can be relatively poor. Finally, it has a negative impact on the reliability of the system, for the failure of one of the amplifiers disrupts service to all premises downstream of the point of failure.

Second, while two-way transmission is possible, it is evident that as the signal travels

112. In an earlier study of costs for a PCS system with dense cell sites, Hatfield Associates concluded the cost per subscriber could be in excess of $15,000 under a low-penetration scenario.

113. Petersen, Phil, "Positioning PCS on the Telecom Landscape," *Telephony*, December 13, 1993. The article further suggests that the maximum operating speeds for PCS will be pedestrian, but vehicular for cellular; average PCS suburban cell radii will be 0.25 mile (about 400 m) and 2.5 mile for cellular; a 32 kbps waveform coder will be used for PCS and a 5 kbps to 13 kbps voice coder for cellular; and the potential handset price range will be $150 to $200 for PCS and $500 to $700 for cellular.

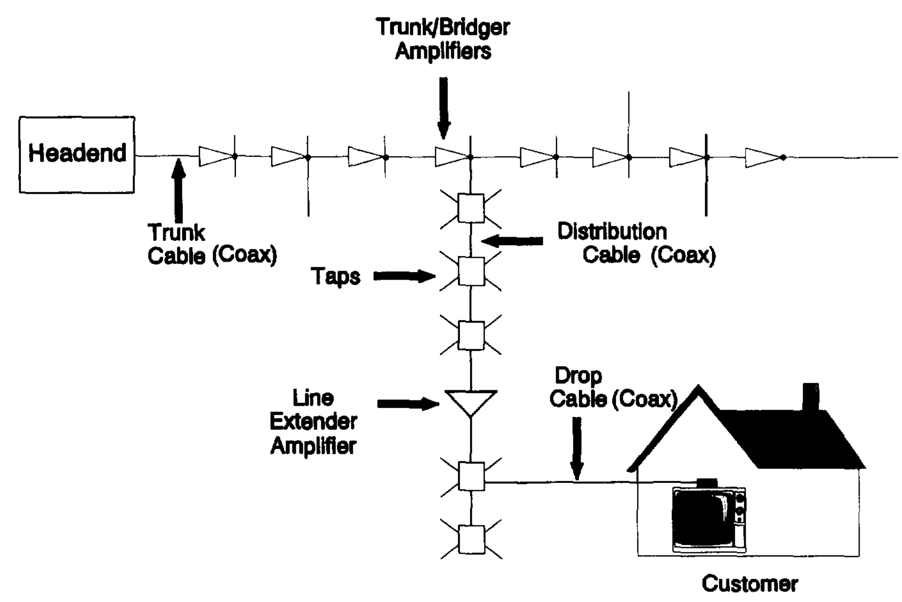

Figure 3.4. Traditional Cable Television Network

upstream, it combines with more and more upstream signals from other premises the closer it gets to the headend. This significantly limits the upstream capacity; more seriously, it means that noise and other interfering signals accumulate as they approach the headend, leading to a substantial degradation in upstream signal quality. As a result, while some cable systems have deployed services involving upstream transmission, the importance and usefulness of those services has been fairly minimal.

Cable television networks are presently undergoing a rather rapid metamorphosis. Attempting to address all of the above problems — quality, reliability, support of applications requiring two-way transmission — the cable industry has begun to extensively deploy fiber optics in the fashion shown in Figure 3.5.

Fiber optics transmission is utilized from the headend out to fiber nodes serving some number of premises — typically, from 500 to 2000 homes at present, with a few systems deploying fiber to nodes serving 100 homes or fewer. The existing coaxial cable is then used for the remainder of the path, which is usually then limited to 1-2 miles in length to any premises. It is estimated that, at present, about 35% of all cable subscribers are served by networks that have been enhanced with fiber in this fashion.[114] A fiber-en-

114. Green, Richard, President and CEO of Cable Laboratories, Inc., keynote address to the ATM Forum, August 25, 1993.

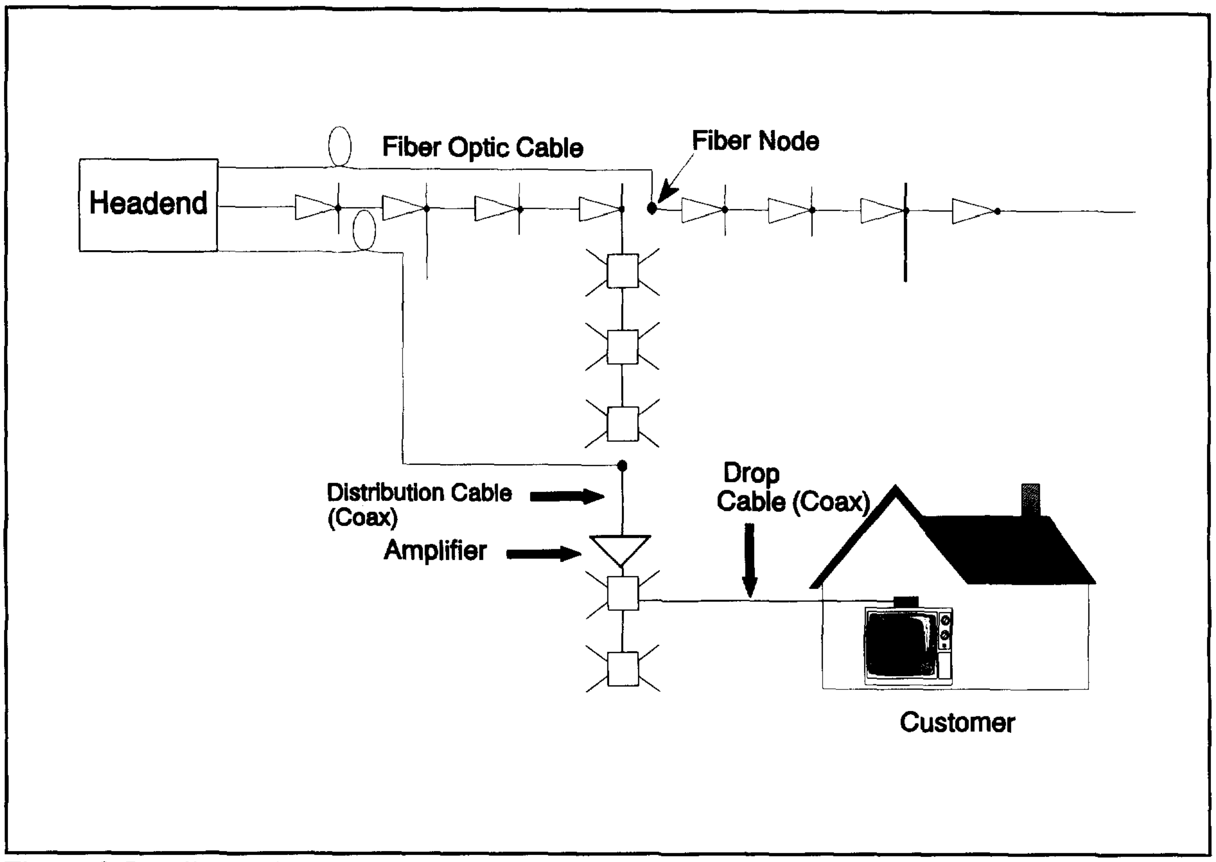

Figure 3.5. Fiber-Enhanced Cable Network

hanced network created in this fashion has significant advantages, including:

- better signal quality, due to the high quality of the fiber optics transmission medium and the elimination of the broadband amplifiers required in a coaxial system;
- better reliability, again due to the elimination of most of the amplifier cascade; and
- increased channel capacity.

Concerning the last point, industry experts talk about fiber-enhanced systems capable of delivering 80 channels of broadcast television, and from 300 to 500 additional channels that can be used for targeting specific interest groups, providing video on demand services, and other similar services. These fiber-enhanced systems are capable of committing a considerable amount of capacity to two-way telecommunications services. Thus, the cable industry describes the evolution as being from cable television networks to "full service" networks.

An early telecommunications service candidate on such a fiber-enhanced cable network is a combination of telephony and low-speed[115] data transmission. The technology for cable telephony is well-developed at this point, and several vendors have announced off-the-shelf systems. All such systems normally require the fiber-to-the-node configuration shown in Figure 3.3. The systems use available bandwidth to multiplex digitized voice signals onto one or more of the existing six megahertz (6 Mhz) frequency bands in which standard television signals are normally carried on a cable system. However, as the signal is multiplexed and formatted, all of the proposed systems will interface with the exchange switch with normal telephone circuits or trunks with associated standard signaling. From the vantage point of the switch and the subscribers' terminal equipment, the cable system provides a transparent replacement of the existing LEC "loop."

The list of vendors which have systems, or have announced near-term availability, include, among others: Scientific-Atlanta; Optical Networks International/AT&T; General Instruments Corporation (Jerrold Communications); and First Pacific Networks (FPN). With one exception, FPN, the systems address only transmission between the premises and exchange switch. The switch itself, and other important local exchange functions like billing, interconnection, operator services, and directory services, must be added to the cable telephony network, or be provided by other parties.

The CoAccess™ system from Scientific Atlanta,[116] depicted in Figure 3.6, is a typical example of such a system. Its components are a subscriber unit at the premises, and a telephony interface unit at the headend. Between the premises and the headend, it makes use of the hybrid fiber-coaxial network discussed above, including the existing optical-electrical conversion equipment installed at the fiber node.

The network side of the subscriber unit connects to the coaxial distribution cable. On the premises side, the unit's outputs include coaxial cable for the provision of normal television service, and two, two-wire telephone lines. The latter can be configured to provide ISDN Basic Rate Interface and other digital data services. In addition to the standard voice lines, there are optionally two additional lines for data, facsimile, security, energy management, and other applications. All four lines are implemented as 64 kbps digital signals on the network.

The subscriber unit is powered from the network, and therefore requires no connection to the subscriber's electrical power. The unit also has remote diagnostics to isolate problems. The system offers 480 simultaneous voice channels using demand-assigned frequency division multiplexing in the otherwise-unused upstream part of the normal cable spec-

115. 64 kbps data circuits, possibly formatted to provide the Integrated Services Digital Network (ISDN) Basic Rate Interface.

116. *CoAccess CATV Telephone System, A Dual Telephony/Video System for CATV Networks*, brochure by Scientific Atlanta, Atlanta, Georgia, 1993.

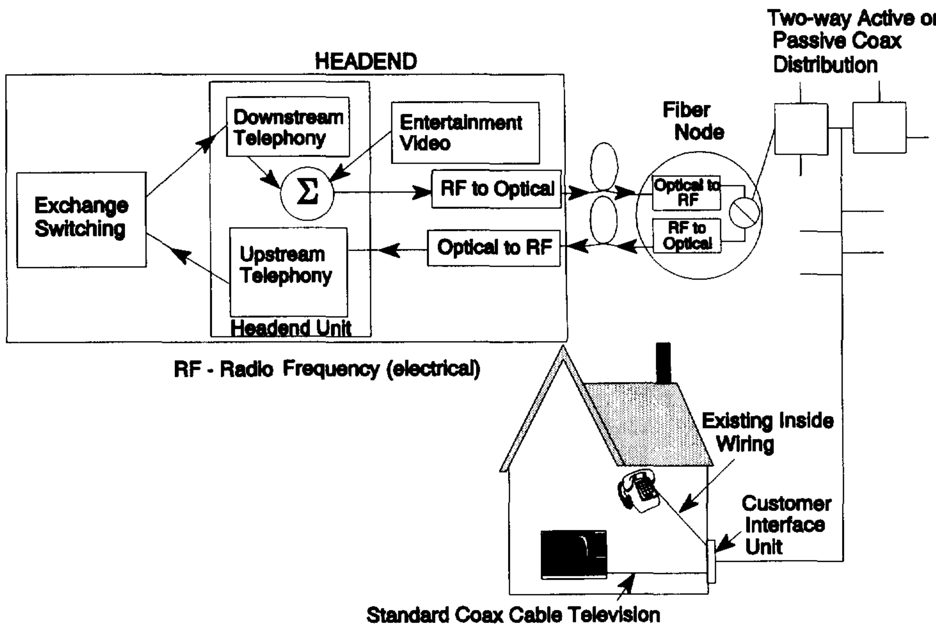

Figure 3.6. Telephony Over a Cable Television Network

trum, which is located from 5 to 30 Megahertz (MHz). In the downstream direction, it uses a time-division multiplexed digital stream, with time slots assigned to each subscriber. All customers can be served using from one to a few 6 MHz frequency bands in the downstream direction in a frequency range above that used for carrying analog and digital video signals, minimizing the consumption of system capacity that would otherwise be available for other purposes.

The headend unit converts downstream telephone signals from the exchange switch into a TDM bit stream modulated into the assigned 6 MHz frequency band(s), then combines it with the video signal being broadcast over the system. In the upstream direction, it recovers the individual voice signals from a composite frequency-multiplexed analog signal, and provides POTS, T1, or E1 interfaces to the exchange switch. The switch interface meets applicable Bellcore specifications.[117]

117. Those specified in Bellcore documents TR-TSY-000057, TR-TSY-000008, and TR-TSY-000303.

3.5 Fiber Rings

Fiber Rings are a relatively new phenomenon in local exchange telecommunications. While they have been installed by both LECs and CAPs, we will focus on the latter case.

In the typical fiber ring scenario, shown in Figure 3.7, a CAP runs a fiber sheath containing multiple fiber strands around telecommunications-intensive areas, which today typically means the downtown areas of major cities. Within, or close to, the premises of each customer, the provider locates an add-drop multiplexer (ADM). The ADM provides the customer with access to circuits providing standard bit rates, typically T1 (1.5 Mbps), T3 (45 Mbps), and SONET OC-3 (155 Mbps). This is done at both end points of the desired circuits. The end points may be any mixture of customer premises, exchange carrier end offices/tandems,[118] or IXC POPs. The CAP may run extensions from an ADM on the ring to those customers' premises which are not proximate to the ring. Typically, however, such extensions are not run very far from the main ring. There is some effort underway to interconnect downtown rings with "suburban" rings serving data-intensive areas such as office, research, and industrial parks.

The CAPs have come into existence primarily as providers of point-point dedicated circuits. For a CAP to provide competitive switched exchange telecommunications services, it must either install its own switch, as shown in the figure, or lease switch capacity from one or more other carriers with which it connects. The figure shows the switch as being located in the CAP network control center, the location from which the CAP monitors and controls the ring, and provisions new circuits.

Due to their primary location in traffic-intensive downtown areas and the limited extensions to the main ring, CAP networks typically do not pass large numbers of residences or small businesses. As a result, a CAP is normally not a good candidate to provide exchange services competition to the general marketplace, at least not by itself. More likely is the use of a CAP network in conjunction with one or more cable networks to reach businesses and residences.

The mapping of the CAP ring to the generic model is less obvious than for the other technologies, because the customer connection, backhaul, and interoffice facility can all be provided on the same ring. We treat the customer connection component as non-existent except in the case of a ring extension. The ADM at (or near) the customer premises is considered to be the remote terminal. The backhaul and interoffice facility are both taken to be the ring itself.

118. The degree to which CAPs provide circuits that have one end in a LEC end office or tandem is highly dependent on the regulatory status of CAP and LEC interconnection.

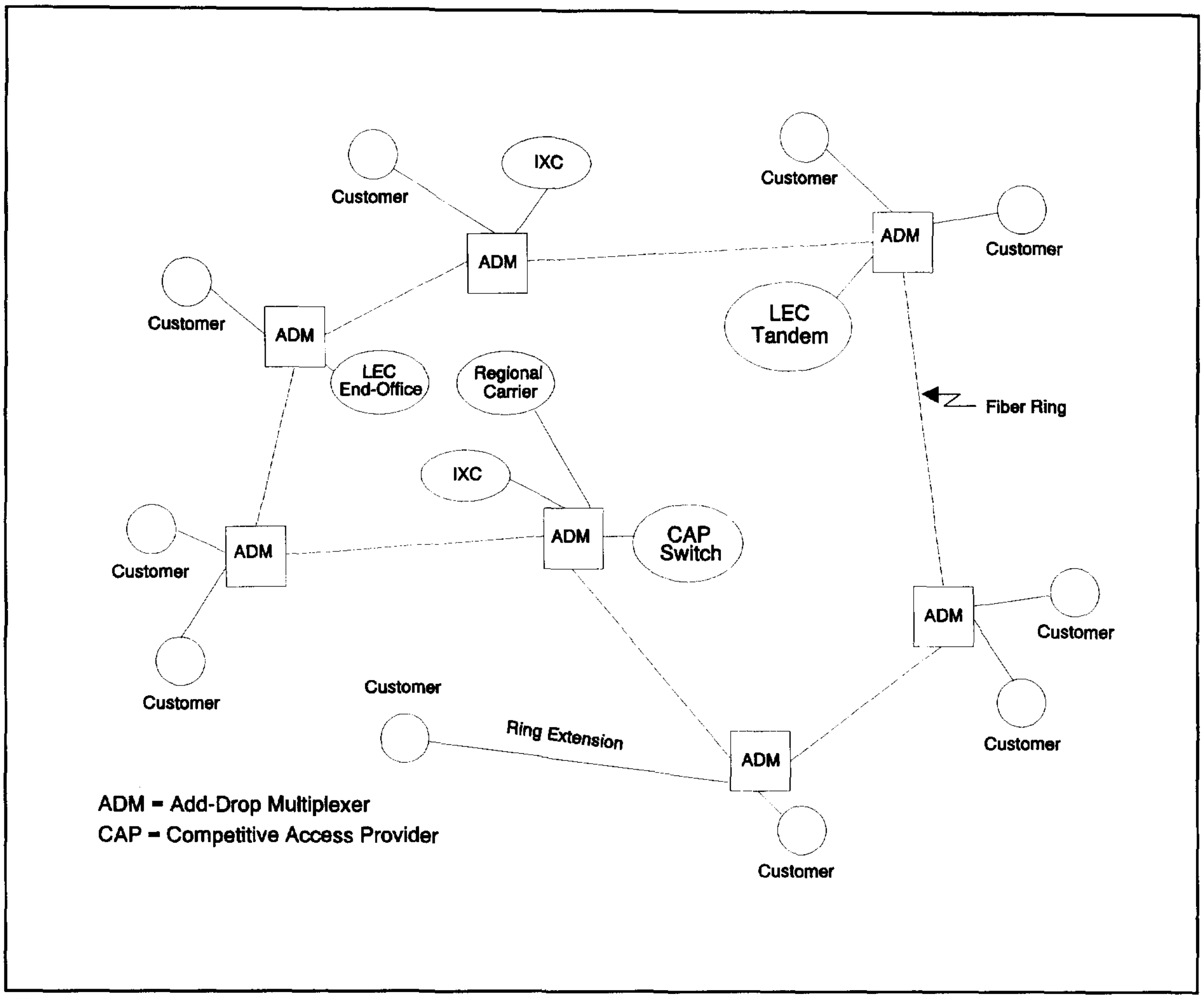

Figure 3.7 A Competitive Access Provider (CAP) Fiber Ring

3.6 Per-Subscriber Technology Costs[119]

Table 1 maps each of the alternative distribution technologies that have been introduced to this point to the generic model introduced in Figure 3.1. For comparison purposes, it also maps the exchange LEC architecture into the generic model.

Given these mappings, we have used the following methodology to arrive at the costs associated with the various technologies. First, we developed a typical deployment scenario. In this scenario, there is a service area containing 80,000 homes. Consistent with figures that pertain to a typical cable system, residential lots have a 105 foot frontage,

119. Hereinafter, we refer to the capital investments associated with acquiring and installing the technology components as "costs."

Table 3.1

Mapping of Specific Technologies into the Generic Model

Component	**Cellular Radio/PCS**	**Cable Telephony**	**CAP Fiber Ring**	**LEC Network**
Signaling	SS#7 Network	SS#7 Network	SS#7 Network	SS#7 Network
Interoffice Facilities	LEC Circuits; CAP Ring	LEC Circuits; CAP Ring	Fiber Ring	LEC Circuits
Switch (Wire Center)	MSC	Switch (Head-end)	Switch (Network Control Center)	Switch (Central Office)
Network Interface Unit	Site Controller	Headend Unit	–	–
Backhaul Facilities	Microwave or Terrestrial Circuits	Fiber Optic Cable	Fiber Ring	Feeder Plant (loop carrier)
Remote Terminal	Radio Site	Existing RF to/ from optical converter	ADM	Serving Area Interface
Customer Connection	Airwaves and Transceiver Unit	Coaxial Cable and Subscriber Unit	None (or ring extension)	Distribution Plant (wire pairs)

which, considering both sides of the street, mean there are approximately 100 homes per mile. The lot has an average depth of 125 feet, yielding an average lot size of 12,500 square feet, about 1/3 of an acre. This corresponds to 2,230 homes per square mile. Finally, the alternative provider attains a 10% penetration — that is, it serves 10%, or 8,000, homes in this service area.

The cost results may *a priori* have a significant dependence on these key assumptions, namely:

- the linear and area density of homes;
- number of homes passed;
- the penetration figure; and
- whether the new technology is serving only residences, or a mix of residence and

businesses.[120]

Such dependencies are considered in a subsequent sensitivity analysis.

Next, we determined the costs for the components of each distribution technology. The costs of some components, such as the subscriber unit, are truly per-subscriber costs. Others are "lump sum" costs — that is, the component must be deployed in a certain size unit, with the capacity to serve a specified maximum number of subscribers. In such cases, we determine the following quantities:

- D, the cost of a basic unit of the technology;
- d, the cost of increments that can be added to that basic unit;
- S, the maximum number of subscribers the basic unit can serve; and
- s, the number of additional subscribers that can be served by the incremental unit.

If, in the assumed deployment scenario, the number of subscribers served by the component is N, then

- The total cost T of the technology component is given by

  $$T = D + (n * d); \text{ and}$$

- The cost per subscriber, t, of the technology component is given by

  $$t = T/N,$$

where n is the smallest number for which $S + (n * s)$ is larger than N. These equations assume the system is configured with the minimum amount of capacity required to serve the existing customers. *In an actual deployment scenario, of course, the system would have more than the minimum capacity in order to accommodate growth.*

The required cost data were obtained through references in the literature, through conversations with people involved with the corresponding technologies, and, where necessary, through our own judgement, based on our collective industry experience. At a minimum, we have attempted to insure our results are plausible by comparing our total per-subscriber costs of a given distribution technology with benchmark figures commonly quoted by the industry.

Table 2 presents the per-subscriber costs for each component of each alternative

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120. As noted earlier, the Busy Hour CCS for businesses is 50% higher than for residences.

distribution technology, and the total per-subscriber cost of each alternative.[121] Important details on the treatment of individual technologies and their components are summarized below. They apply to both Table 2 and the sensitivity analysis discussed subsequently.[122]

Table 3.2
Per-Subscriber Technology Costs

Component	Cellular Radio	PCS	Cable Telephony	CAP Fiber Ring
Interoffice Facilities	0	0	0	0
Wire Center	60	60	60	60
Switch	190	190	190	190
Network Interface Unit	50	50	225	0
Backhaul Facilities	100	100	40	630
Remote Terminal	2160	400	0	230
Customer Connection	$300	$300	$320	$100
Total	**2860**	**1100**	**835**	**1210**

Components Common to All Distribution Technologies

We have assumed an interoffice facility cost of $0 in all cases for the following reason. For the low penetration assumed, a single switch will suffice to serve the entire area covered by the alternative provider. Therefore, the only interoffice facilities are those required to interconnect with the LEC network, and these are included in the expenses associated with the cost of interconnection. In any case, it is likely that most

121. All costs are rounded to the nearest $5 in the table.

122. The figures used in the business case in Chapter 5 represent a larger market size and thus are slightly lower. See Table 3 later in this Chapter for the exact values used in the business case model.

alternative providers, with the exception of CAPs, would obtain such interoffice facilities from the LECs or another provider, as opposed to building them themselves, and those facilities would thus be treated as an expense. Expenses associated with the alternative technologies are dealt with in Chapter 5.

We have estimated that the wire center costs — in land, buildings, engineering, power systems, environmental control systems, cross-connect frames, and the like — are 30% of the total switching cost. This leads to a total of $480,000 in the nominal scenario, which is roughly consistent with Reed's[123] assumption. Of this amount, 15%, or $10/subscriber, is attributed to land; 65%, or $40/subscriber, is attributed to building; and the rest is for engineering and wire center equipment not already accounted for as part of the backhaul facility. This amount is held fixed as switching system costs are varied during the sensitivity analyses.

We have used a common per-line cost for the switching system. This is appropriate, because any special capabilities a particular technology might require, such as the software to control hand-off in cellular and PCS systems, are covered in the network interface unit component, as defined in the generic model. The per-line cost is derived from the following industry benchmark: the per-line cost decreases from $200 per line for very small switching systems (serving 500 lines) to about $90 per line for large systems (serving around 80,000 lines). We have done a linear extrapolation between those two points for the number of lines served, both here and in the subsequent sensitivity analysis. The per-line costs this algorithm yields are fairly consistent with the numbers used in analyses we reference later by David Reed and by Hughes Network Systems.[124]

Cellular Radio

For both cellular radio and PCS, the extra cost associated with control of hand-off has been assumed to be 25% of the switching cost, consistent with current AMPS systems. It is shown in the above table in the Network Interface Unit category, since among other effects, it serves to provide a static circuit interface to the switching system as calls are handed off cell to cell.

Strictly speaking, hand-off would not be necessary if a system served *only* fixed locations. But it is our expectation that both cellular and PCS will continue to offer both fixed and mobile service, and in fact will integrate the two kinds of service — that is,

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123. Reed, David, "Putting It All Together: The Cost Structure of Personal Communications Services," Federal Communications Commission, OPP Working Paper Series, Number 28, November, 1992.

124. "Fixed Cellular Economics for Wireless Telephony," paper by the Digital Cellular Networks Division of Hughes Network Systems, Inc., Germantown, MD, December, 1993.

allow customers to use either a portable or fixed terminal in conjunction with the PCS service they purchase. Furthermore, the hand-off control software in today's, and possibly tomorrow's, mobile switching systems is not readily separable from the remaining switch software.

For both this case and PCS, we have determined the backhaul costs using T2 microwave radio systems costs. This yields a cost of $80,000 for a system capable of serving approximately 800 customers, or $100 per customer; the system is assumed to be available in increments of 800 subscribers. There must be one such system per radio site.

The cost of the remote terminal — the cellular radio site — may seem inordinately high for cellular, especially in light of the fact that the total cellular infrastructure cost, including all components of the system, is only about $1000.[125] The explanation lies in the greater capacity required in a cellular system providing fixed-location telephone service. As we have discussed earlier, cellular per-subscriber usage is much lower than those for wireline telephone subscribers, typically only about 0.7 CCS, versus 3.6 CCS for residential telephone customers, and around 5.4 CCS for business customers. Providing this extra capacity dramatically increases the radio site costs. *Scaling the existing radio site cost to reflect the higher usage figures leads to the result of $2,160. At this level, it is evident that cellular radio is an unlikely replacement for the existing LEC telephone service.*

Since the medium used from the RT to the premises is wireless, the only component of the customer connection cost for either cellular or PCS is the actual interface unit at the premises. We have estimated that unit to cost $300.

PCS

The cellular systems now operating in the U.S. are almost exclusively analog systems. They are commonly called AMPS systems, because their designs are based on a system architecture and control structure developed by Bell Laboratories in the 1970's under the development name "Advanced Mobile Phone Service."

There have been several well-publicized technical advances over the past two or three years that will greatly increase the capacity of cellular systems using digital radio techniques. The Telecommunications Industry Association, the U.S. standards body responsible for developing cellular and other telecommunications standards, has approved two digital cellular standards, IS-54 and IS-95, that will be used by carriers to increase system capacities using the existing 25 MHz of spectrum allocated to each carrier in a market.

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125. Cellular Telecommunications Industry Association, Press Release, March 2, 1993.

The industry literature is replete with comparisons and capacity-gain studies pertaining to the TDMA and CDMA techniques codified by these new standards.[126] In general terms, one may assume that these techniques may potentially increase a cellular system's capacity by a factor of ten to twenty if the entire allocation is converted to digital operation. Our substantially lower cost for the PCS radio site — $400, versus $2,160 for existing cellular systems — reflects the effects of these capacity increases.

For PCS, we have determined the per-customer remote terminal (e.g., radio site) cost based on the following figures:

- A single site is capable of serving approximately 8,000 customers. This figure is derived from the current AMPS limitation of 800 customers, and an expected ten-fold capacity gain in PCS systems.

- Each site requires a fixed investment in land and buildings of $300,000.

- The per-customer cost of radio equipment is $360, available in increments of 800 customers. This figure derives from the current cost of an AMPS system, combined with the determination that systems will have ten times as much capacity at twice the cost.

Cable Telephony

The Network Interface Unit is the element that must modulate and demodulate the video signal and telephone signals in the composite signal sent to premises, appropriately multiplex and demultiplex the digital telephony bit stream, and assign upstream channels on a demand basis, and the like. Based on information on the approximate costs for typical systems, and used that information to build a cost model that can be applied to the nominal scenario and each scenario considered in the sensitivity analysis. As expected, since this is a hardware element, as opposed to the software element used for the AMPS and PCS system, its cost is considerably higher than for the cellular case.

In discussing the cost of telephone service, the cable industry posits that the network capacity required for both upstream and downstream transmission of the telephony signal is already in place and is free. In reality, however, the upstream transmission capability has not been implemented on the coaxial portion of most hybrid fiber-coaxial cable systems. Furthermore, It does not seem reasonable that the spectrum should be considered to be free on either the fiber or coaxial portion of the system, since its use for tele-

126. *See*, e.g., Salmasi, Allen, and Klein S. Gilhousen, "On the System Design Aspects of Code division Multiple Access (CDMA) Applied to Digital Cellular and Personal Communications Networks," IEEE Vehicular Technology Conference Proceedings, 1991; Sweeney, Dan, "The Quest for Spectrum Efficiency," *Cellular Business*, June, 1991.